NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3534

INSTRUMENTATION FOR MEASUREMENT OF FREE-SPACE SOUND PRESSURES IN THE IMMEDIATE VICINITY OF A PROPELLER IN FLIGHT

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SUMMARY

Instrumentation suitable for making in-flight measurements of the free-space sound pressures in the immediate vicinity of a propeller in forward flight has been developed and successfully used on a fighter airplane up to a Mach number of 0.72. The sensing element is a capacity microphone housed in a streamlined probe and used in conjunction with an oscillator to convert the pressure pulses into a frequency-modulated signal which is telemetered to the ground. At the ground receiving station, the telemetered signal is detected and recorded on magnetic tape. Subsequently, the recorded signal is converted to a varying voltage which is fed into a heterodyne frequency analyzer.

The system response is flat within ±1 decibel in the frequency range of 80 to 1,000 cps, and the maximum second-harmonic distortion is less than 3 percent for a sound level of 140 decibels (re 0.0002 dyne/cm^2). The overall accuracy of the system is ±2 decibels, and the dynamic range is 150 to 113 decibels (re 0.0002 dyne/cm^2).

INTRODUCTION

In recent aeronautical research, much attention has been given to the characteristics of the sound field generated by airplane propellers moving in forward flight at various speeds. Most of this work has been theoretical (refs. 1, 2, and 3), and attempts to verify the theories experimentally have been limited to sound-pressure measurements made inside the fuselage or on the skin of the airplane. In order to obtain data (ref. 4) which are more directly applicable to these theories, it was necessary to develop instrumentation and a technique suitable for making free-space sound measurements in the immediate vicinity of a propeller moving at high forward speeds.

Since the data needed for evaluation of these theories would have to be presented in the form of harmonic analyses, consideration was given to the techniques for obtaining frequency analyses from pressure data. The technique selected was that of recording the data on magnetic tape, the data then being available in the form of an electrical signal which could be conveniently fed into any one of a number of commercially available, automatic frequency analyzers. Film records of the sound-pressure variations could also be easily obtained from the tape recording by playing the recorded signal into any suitable time-history recorder. Since the available tape recorders which were capable of recording data of this nature with the required fidelity and which were compatible with existing equipment were not suitable for use in fighter airplanes in flight, it was necessary to telemeter the information to the ground.

Although usable in other applications, the instrumentation described in this report was specifically developed for measuring the free-space sound field near the tip of a propeller of a fighter airplane in forward flight (ref. 4). In these tests, the frequency range of interest was 80 to 1,000 cps. Figure 1 presents a frequency analysis typical of those obtained with this equipment. The results of these tests are presented in detail in reference 4.

DESIGN AND DESCRIPTION OF SYSTEM

Block diagrams of the telemetering and analyzing equipment are shown in figure 2.

The sound-sensing part of the system consists of a microphone housed in a specially designed probe. The microphone converts the pressure pulses into capacity changes, and an oscillator, which is potted inside the boom directly behind the microphone, converts the capacity changes into a frequency-modulated signal which amplitude-modulates a telemeter transmitter. The signal is then detected by a ground receiver and recorded on magnetic tape for future analysis. The analyzing process consists of passing this electrical signal through a heterodyne frequency analyzer, then through a voltage-squaring unit, and, finally, to a pen recorder.

Microphone

In the selection of the microphone, a number of factors were considered: the amount of additional equipment necessary to convert the information into a frequency-modulated signal, the temperature, humidity, and acceleration characteristics of the microphone, and the microphone size and frequency range. The capacitance-type microphone was selected as being the most suitable of the commercially available microphones, and the Western Electric type 640-AA was chosen on the basis of highest sensitivity.

The characteristics of this microphone are as follows: (1) Maximum sound level is 151 decibels (re 0.0002 dyne/cm^2), (2) frequency response is flat within ± 1 decibel from 80 cps to 1,000 cps, (3) static capacitance is 50 $\mu\mu$f, and (4) sensitivity is 2.2 $\mu\mu$f/in. H_2O. The sensitivity variations of the microphone with altitude and temperature are given in reference 5. The variation with altitude is of the order of 2 decibels for a change in altitude from sea level to 40,000 feet; the variation with temperature is approximately 1/2 decibel for a decrease in temperature of 65° C.

The Western Electric type 640-AA is constructed with a pressure-equalizing leak to the inside of the microphone to minimize the effects of slow changes in ambient pressure. Tests on the unit revealed that approximately 4 seconds were required to reduce a pressure difference by 63 percent at sea level. Since the airplane was required to dive to reach higher Mach numbers, calculations were made to determine the effect of this 4-second time constant during the dives. During a 30° dive at a Mach number of 0.75 and an altitude of 20,000 feet, the rate of change of pressure altitude (4 in. H_2O/sec) would deflect the microphone diaphragm almost full-scale, and little dynamic information could be obtained. Therefore, the leak path (fig. 3) of the microphone was modified by increasing the surface roughness of the ceramic insulator with a diamond-tipped stylus, and a time constant of 0.25 second at sea level was obtained. This time constant permits sufficient pressure equalization to take place during the required dives.

Figure 4 presents the maximum sound level which could be measured, plotted against the rate of change of ambient pressure for various time constants of the microphone leak path at several altitudes. For example, at an altitude of approximately 18,000 feet and a dive rate (rate of change of ambient pressure) of 6 in. H_2O/sec, the maximum sound level which could be measured with the modified microphone would be approximately 139 decibels. The time constant varies directly with viscosity and inversely with pressure as shown in reference 6.

A static calibration of the microphone-oscillator assembly was performed by applying pressure to the outside of the microphone and measuring this pressure with a precision water manometer. A pressure change of ± 1.13 in. H_2O, corresponding to a level of 140 decibels (re 0.0002 dyne/cm^2), produced a frequency change of approximately 500 cps, which is sufficient to give the desired accuracy. Figure 5 is the static-calibration curve for the modified-microphone—oscillator assembly.

In the frequency range of 80 to 1,000 cps, the diaphragm deflection is affected by the spring constant of the air behind it. Therefore, a correction to the static calibration of -1 decibel at 20,000 feet or -2 decibels at sea level must be made (ref. 5).

From the static-calibration curve, second- and third-harmonic distortions were calculated. Under the worst condition, a pressure of -2 in. H_2O across the diaphragm and a sound level of 140 decibels, second-harmonic distortion was less than 3 percent and third-harmonic distortion was less than 1/2 percent.

Probe

In designing the microphone housing, an effort was made to eliminate, insofar as possible, any errors it might introduce into the measurements. The most satisfactory probe would generate little or no aerodynamic noise, and the characteristics of its acoustic chamber would (1) permit an unattenuated and constant-amplitude response over the frequency range of interest, (2) attenuate all frequencies outside this frequency range, and (3) be essentially unaffected by changes in altitude. On the basis of tests described later, the probe was designed as shown in figure 6.

Essentially, the probe is a tube with an outside diameter of 1.25 inches, an inside diameter of 1.0 inch, and an ellipsoidal nose. In order to admit the sound pressures to the microphone, 10 holes, each with a 0.031-inch diameter, were equally spaced around the periphery at a distance of approximately 10 diameters from the nose. An acoustic chamber was formed in the pipe by a plug located upstream from the holes and the diaphragm of the microphone on the downstream side. By a change in the position of the plug, the natural frequency of the acoustic chamber was adjusted to approximately 1,650 cps, so that a flat response could be obtained in the region of interest while maximum attenuation of other frequencies could be achieved.

Tests of the probe-microphone assembly were performed to determine the number and size of the holes required to give negligible attenuation to the sound in the frequency range of interest. These tests were as follows:

The amount of sound attenuation and the natural frequency of the acoustic chamber are dependent upon the number and size of the holes in the probe. In order to arrive at a reasonable configuration with which to begin some tests, computations were made by using the formula for a Helmholz resonator.

Since the minimum diameter of the chamber was fixed by the size of the microphone, and the desired natural frequency was known, the total area of the holes necessary for a reasonable chamber volume could be estimated.

Tests with a loud speaker as the sound source were made at a sound level of approximately 85 decibels. The procedure was to measure the microphone output through a frequency range of 100 to 3,000 cps with the nose section of the probe off, in which case the microphone was completely uncovered, and then with the nose section of the probe in place. This procedure was repeated for different numbers of holes and different chamber volumes with the acoustic natural frequency kept around 1,600 cps. These tests showed that, for 10 holes, the sound attenuation was approximately 1/2 decibel and the natural frequency could be adjusted to the desired 1,650 cps.

The unit was also checked at a simulated altitude of 20,000 feet. Figure 7 presents the frequency response at sea level and at 20,000 feet. It shows the frequency response to be flat within ±1 decibel from 80 to approximately 1,000 cps and then to rise at the apparent natural frequency.

Tests were also made in a 9-inch by 18-inch blowdown tunnel to determine the amount of aerodynamic noise generated by the probe. The probe was mounted on the wall inside the tunnel, and the data were recorded during runs at Mach numbers of 0.5 and 0.7 for angles of attack of 0° and 5° at a simulated altitude of approximately 10,000 feet. The probe was then removed from inside the tunnel and mounted at the same station on the outside of the tunnel wall. Data were again taken during runs at the same Mach numbers.

Overall noise levels of 113 and 110 decibels were measured on the inside and outside of the tunnel, respectively, in the frequency range of 80 to 1,000 cps. On the basis of these data, the overall level of the self-generated noise was 113 decibels or less.

Telemeter

Two channels of a telemeter of NACA design have been packaged especially to suit the airplane used in the tests of reference 4. Figure 8 shows the telemeter and boom installation in the wing compartment of the airplane. The data channel (150 kilocycles) utilizes the microphone capacity as part of the capacity in the tuned circuit of its oscillator; a change in microphone capacity produces a change in oscillator frequency. Switching a capacitor in the tuned circuit of the oscillator of the other channel (110 kilocycles) produces a 500-cps shift in frequency; this shift is used to identify the beginning and end of each test run in order to correlate the telemetered information with data recorded in the airplane. The channel oscillators drive a common modulator which, in turn, amplitude-modulates a 10-watt transmitter operating on a 217.55-megacycle telemeter frequency. The telemeter signal is detected by the receiver, and the two channels (110 and 150 kilocycles) are separated by filters, heterodyned to 3 kilocycles, and recorded on a dual-channel tape recorder.

Analyzer

The frequency analyzer is essentially a frequency-selective voltmeter of the heterodyne type, consisting of a balanced detector, a local oscillator, and a tuned amplifier. The filter used in the analyzer is approximately 20 cps wide at the half-power level, and its response is constant over the tunable range of 0 to 1,500 cps. The converter is a voltage-squaring unit consisting of a vacuum thermocouple having a time constant of 1.7 seconds. The d-c output is recorded on a strip chart.

The calibration of the analyzing equipment is accomplished by recording a signal of known sound level and frequency on tape and playing it through the system. Figure 1 presents a typical frequency analysis obtained with this equipment.

OVERALL PERFORMANCE AND ACCURACY

The dynamic range of overall sound levels measured by this system is 113 to 150 decibels (re 0.0002 dyne/cm^2). The frequency response is flat within ± 1 decibel in the frequency range of 80 to 1,000 cps, with maximum second-harmonic distortion less than 3 percent and maximum third-harmonic distortion less than 1/2 percent. The system is unaffected by humidity and acceleration; corrections for change in temperature are of the order of 1/2 decibel for a decrease in temperature of 65° C (ref. 5); corrections for a change in altitude from sea level to 40,000 feet are of the order of 2 decibels (ref. 5).

The 0.25-second time constant of the leak path in the microphone at sea level permits sound measurements to be made under varying ambient pressures in the usable range of the microphone.

The system noise level does not exceed 113 decibels in the frequency range of 80 to 1,000 cps. In a frequency analysis such as figure 1, some troughs may extend down to approximately 96 decibels, since, by using a 20-cps bandpass filter, the noise level recorded is reduced by a factor of approximately 50, or -17 decibels.

Operation of this system and reduction of the data are routine and do not require engineering-personnel time. The system, when installed, requires little maintenance. In installation and use, no unusual precautions are necessary. A check calibration made after several flights showed no system sensitivity changes.

The overall accuracy of the system, for overall sound levels between 113 and 150 decibels in a frequency range of 80 to 1,000 cps, is ±2 decibels and the repeatability is ±1/2 decibel.

CONCLUDING REMARKS

Instrumentation has been developed for making free-space measurements in the sound field generated by a propeller in forward flight in the frequency range of 80 to 1,000 cps with an accuracy of ±2 decibels. The system has been used up to a Mach number of 0.72; however, it may be usable to higher Mach numbers and be adaptable to any airplane. The equipment is inherently simple in operation and requires little maintenance.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 1, 1955.

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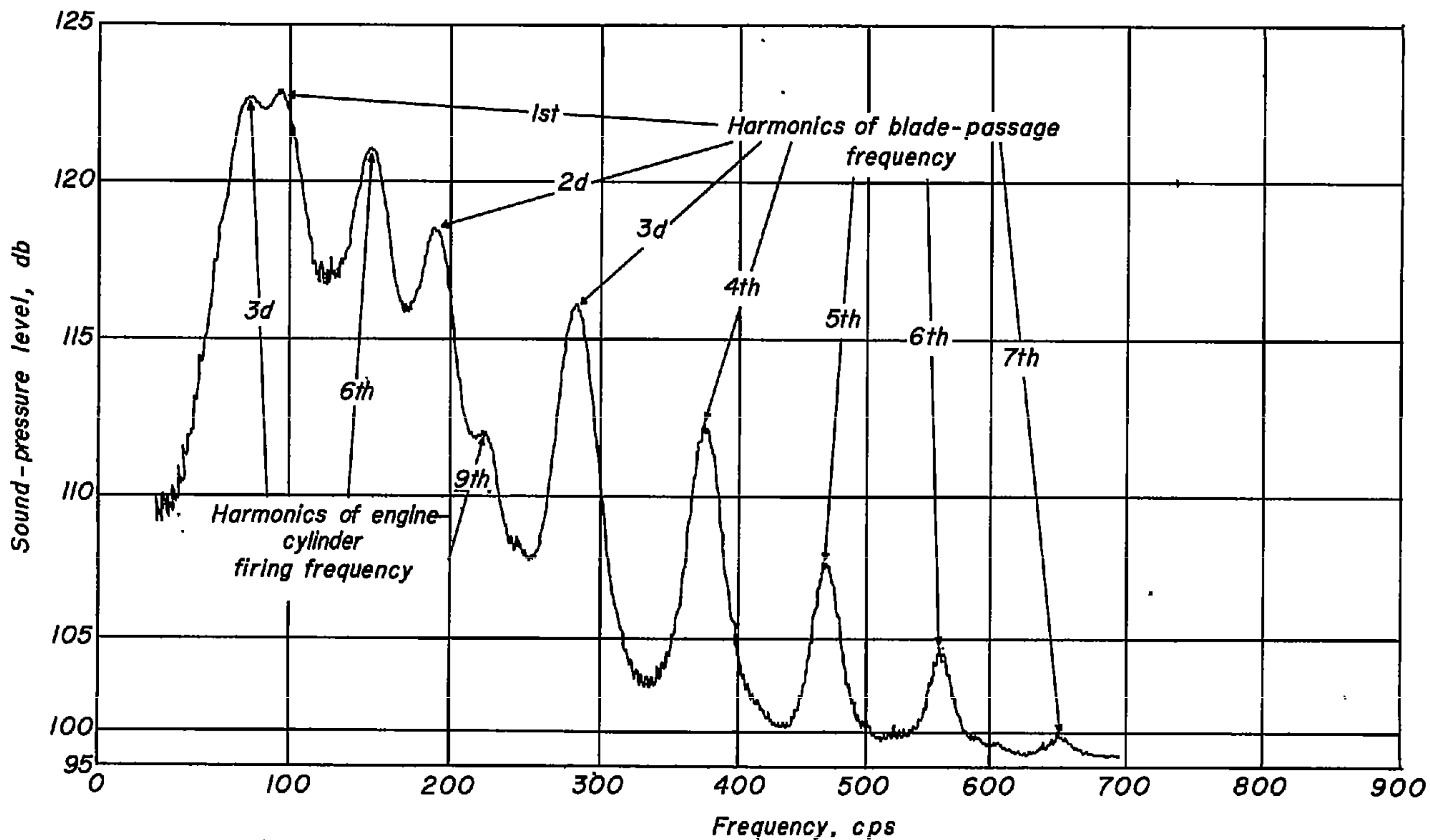
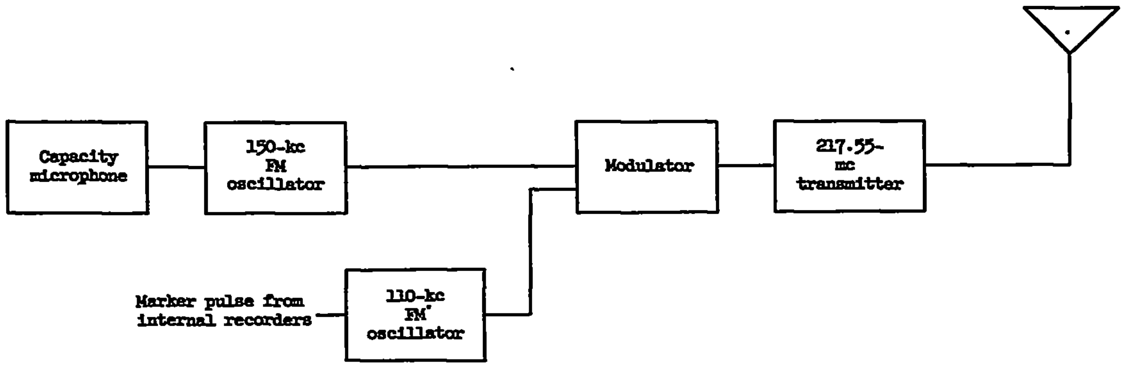
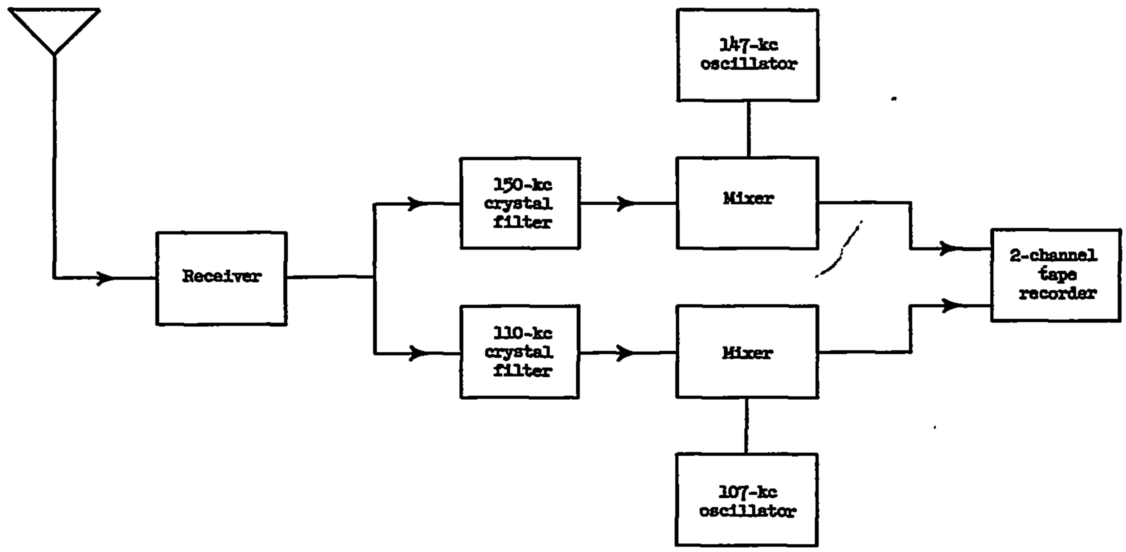


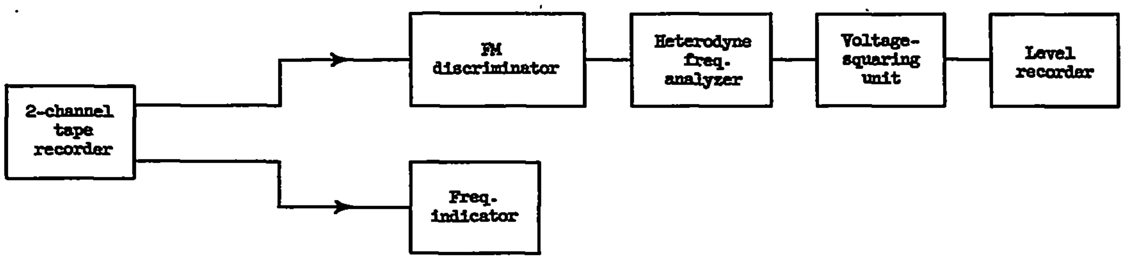
Figure 1.- Typical frequency analysis of data obtained from fighter airplane.



(a) Airplane telemetering equipment.



(b) Ground receiving station.



(c) Frequency-analyzing equipment.

Figure 2.- Block diagrams of telemetering and analyzing equipment.

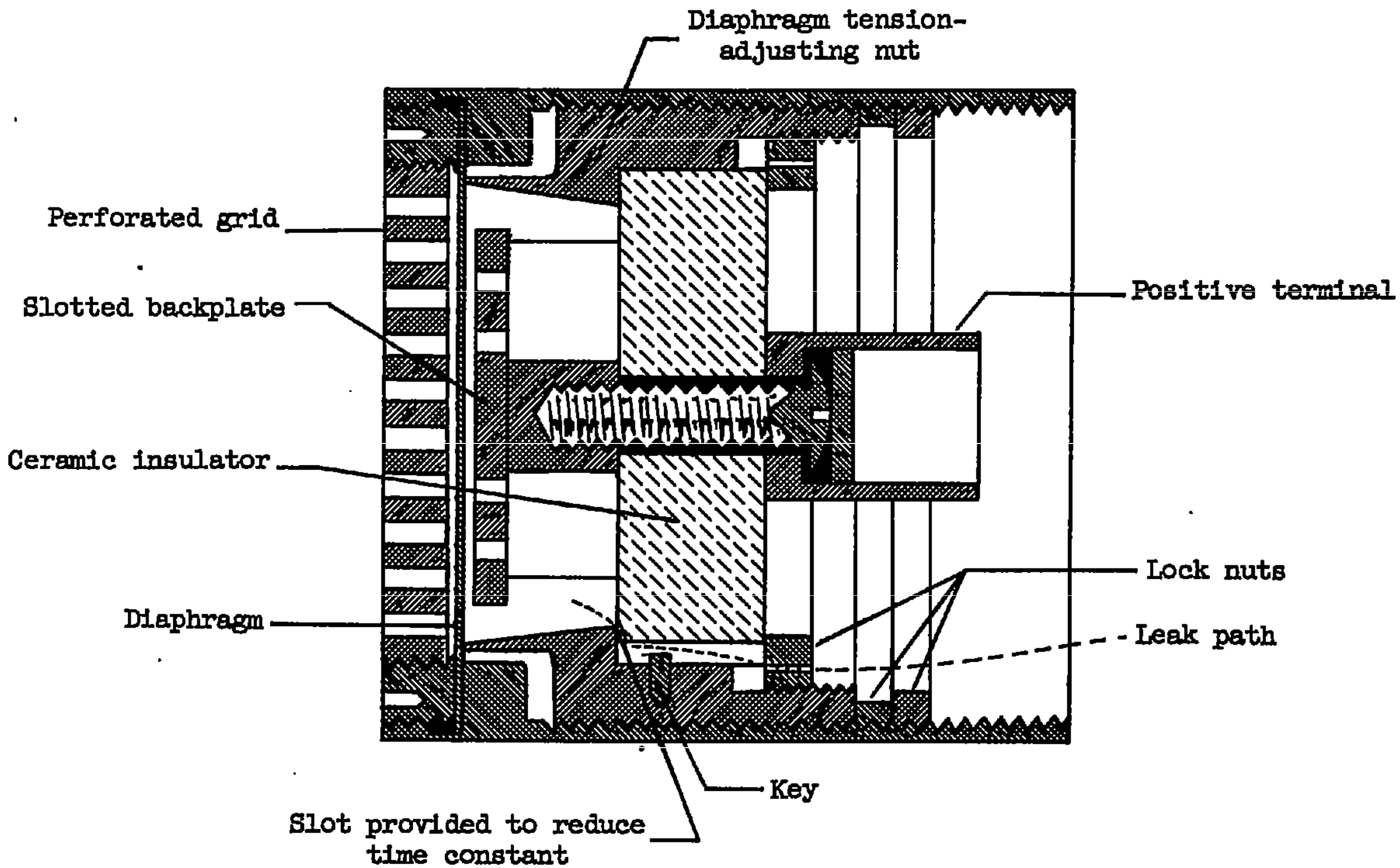


Figure 3.- Sketch of cross section of Western Electric type 640-AA capacity microphone.

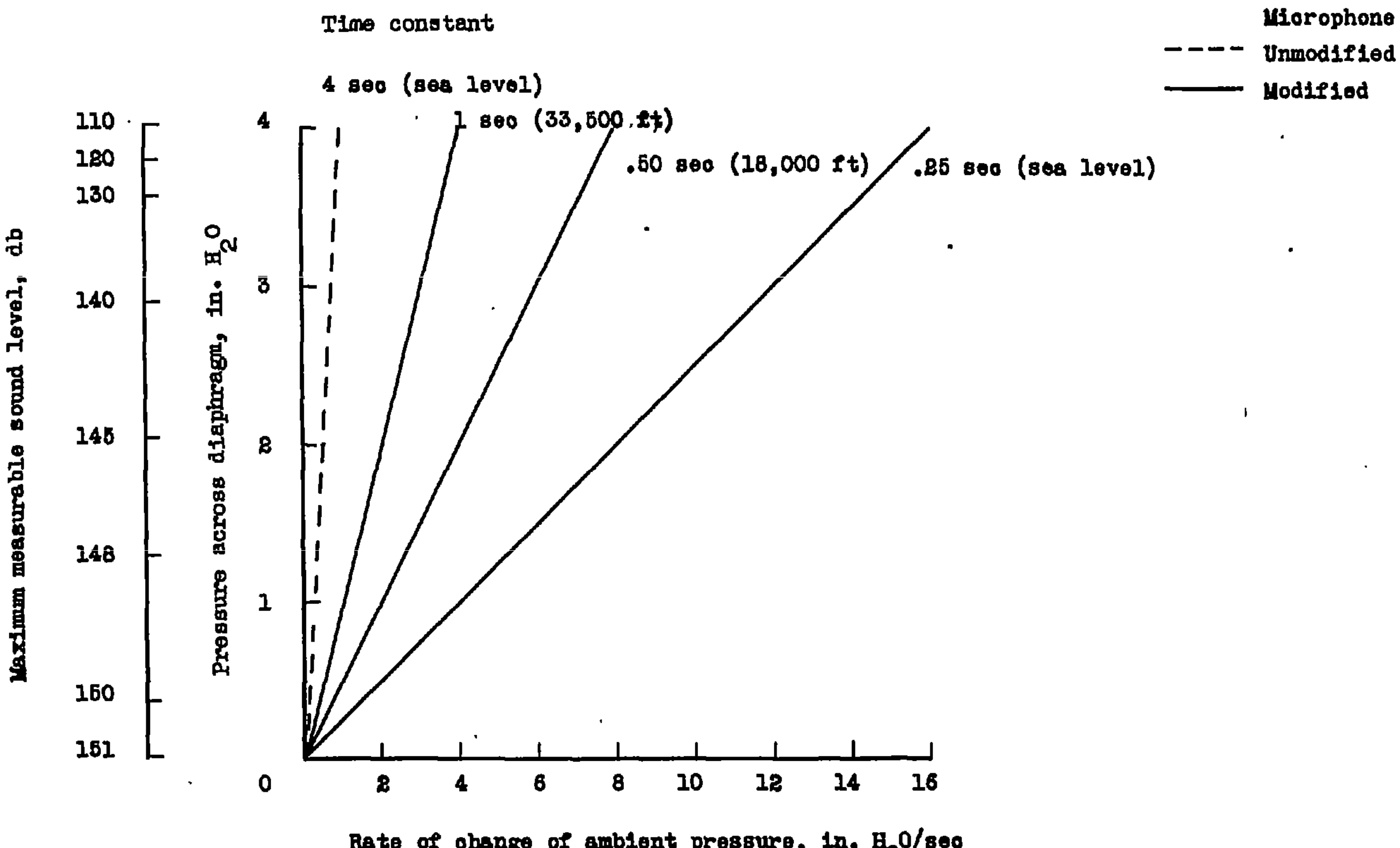


Figure 4.- Effect of time constant and rate of change of static pressure on maximum measurable sound level.

Peak-to-peak pressures, in. H_2O	Sound level, decibels
0.0226	100
.0736	110
.226	120
.736	130
2.26	140
7.36	150

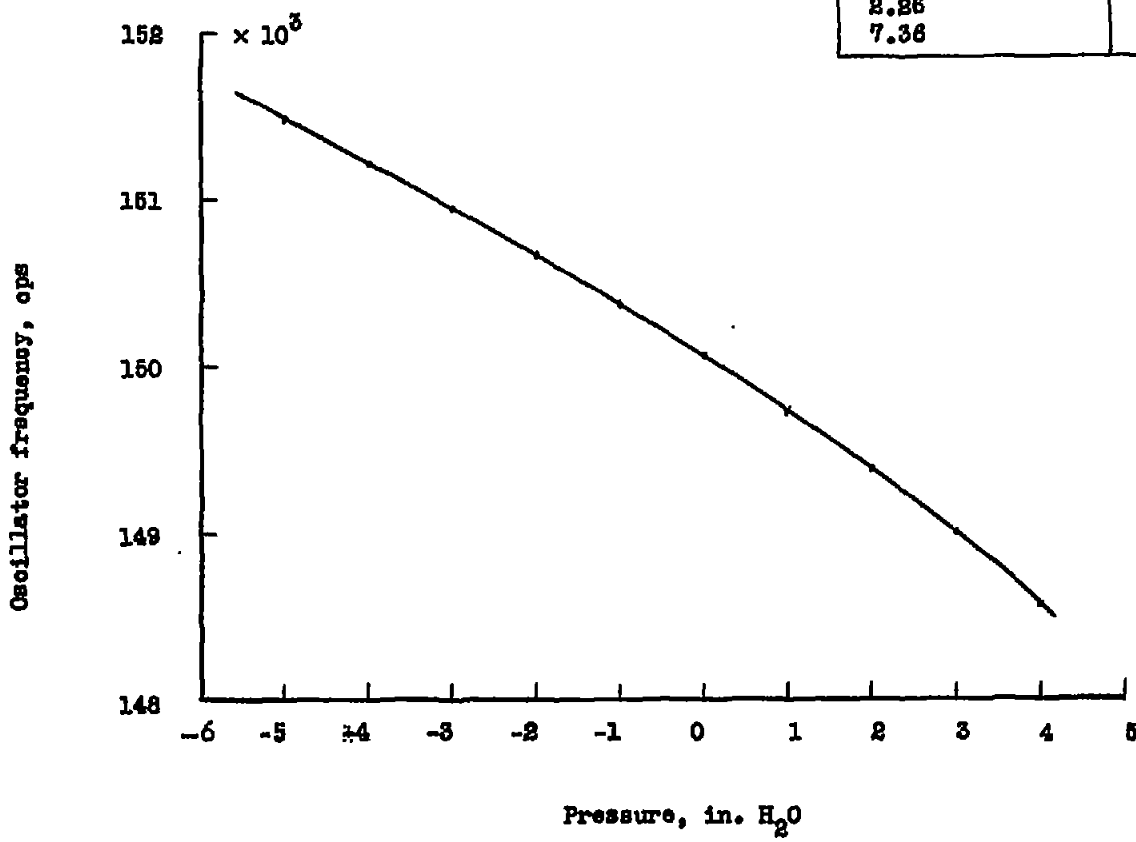


Figure 5.- Static-calibration curve for modified microphone and oscillator assembly.

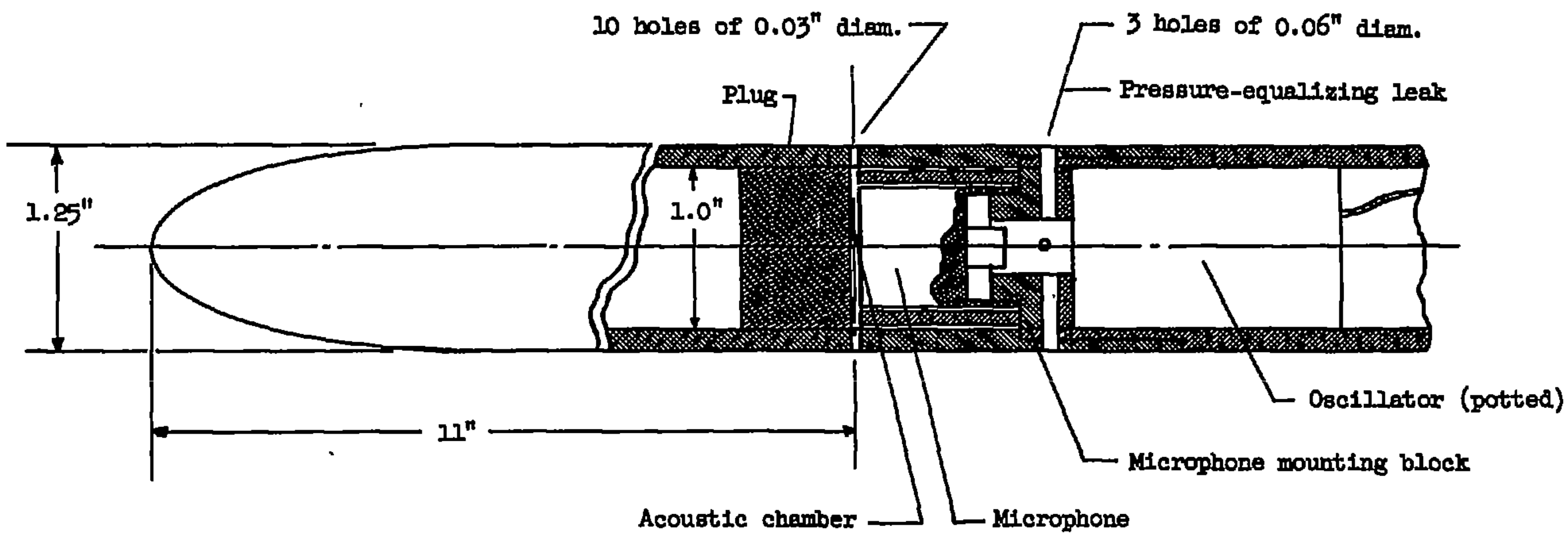


Figure 6.- Sound probe.

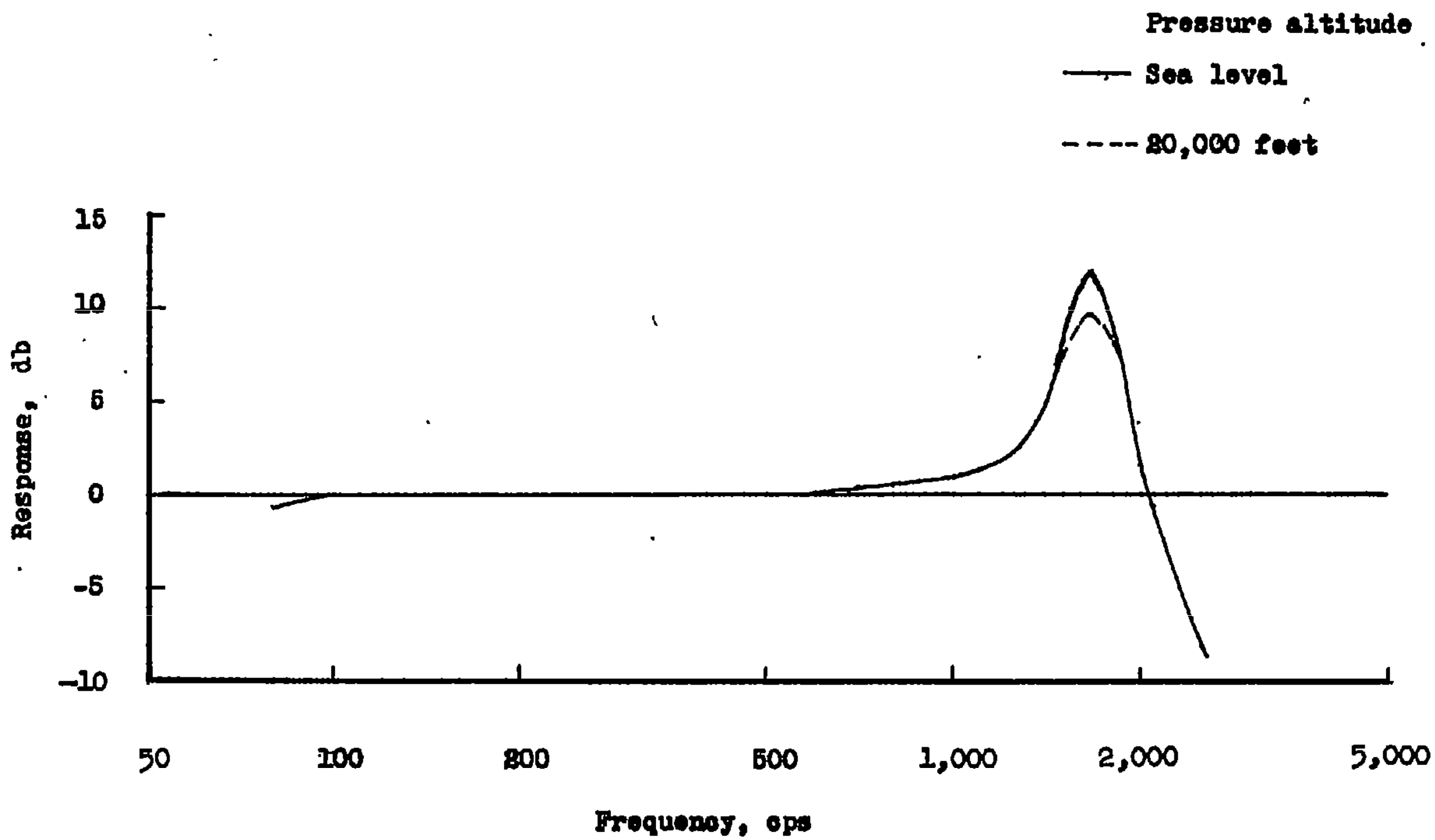


Figure 7.- Effect of microphone housing on frequency response.

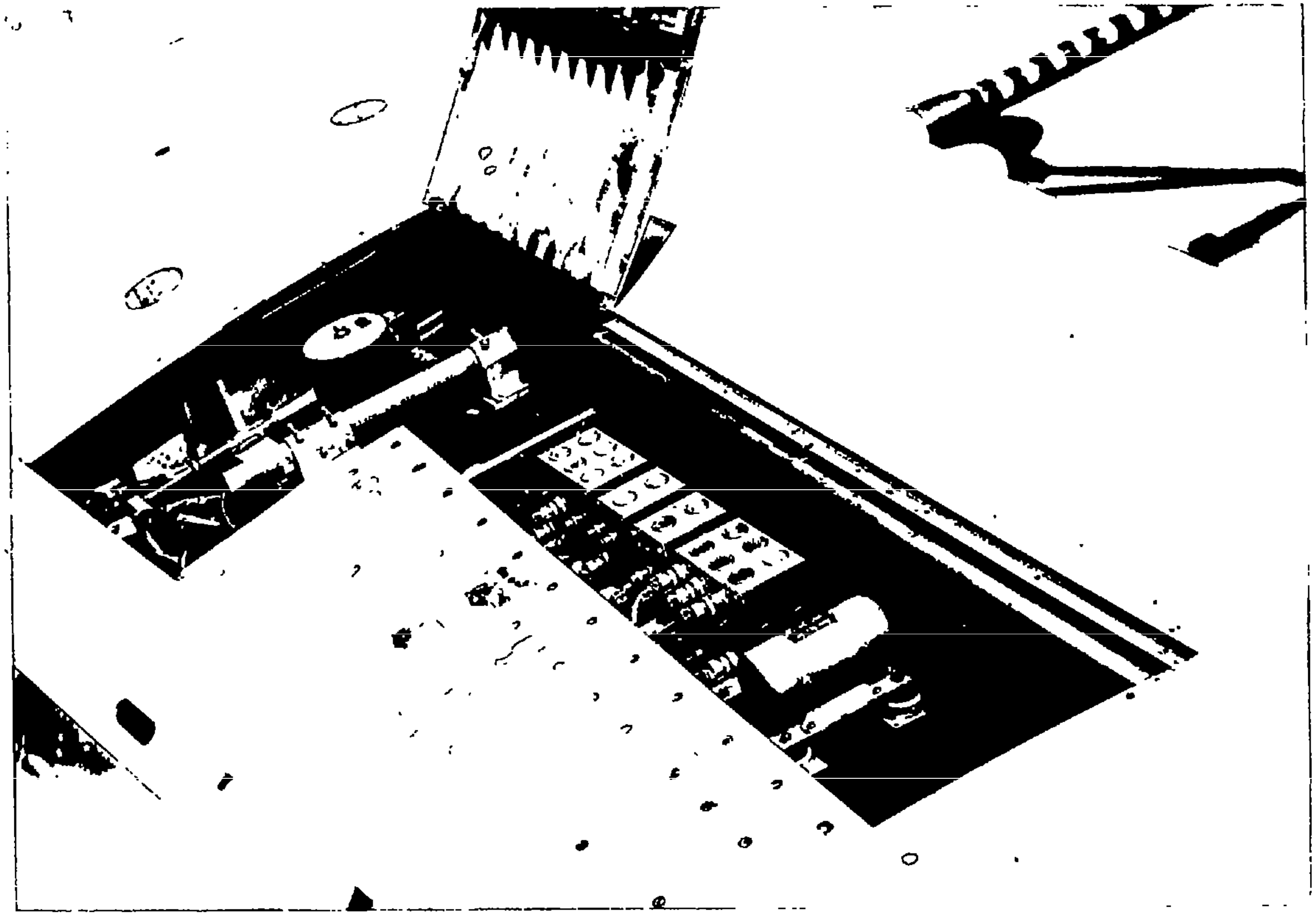


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Figure 8.- Telemeter and boom installation in wing compartment of fighter airplane used in reference 4.

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